

Current and future projections of glacier contribution to streamflow in the upper Athabasca River Basin

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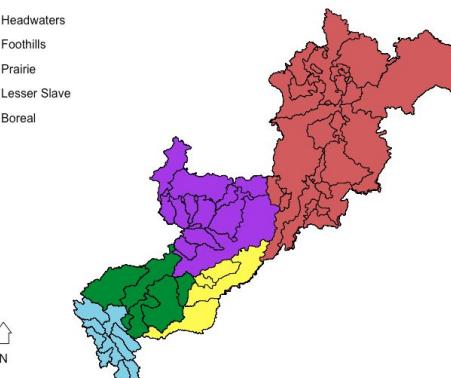


Athabasca River Basin

- Drains ~168,000 km²
- Flows ~1,250 km from the Columbia Icefield (Jasper National Park) to Lake Athabasca
- One of the longest free-flowing (undammed) rivers in the world
- Contains a variety of land use:
 - Jasper NP, Peace-Athabasca Delta UNESCO World Heritage Site
 - Heavily forested foothills
 - Agricultural plains
 - Boreal forest
 - Oil and Gas
- Entire basin modelled as part of the Athabasca River Basin Initiative

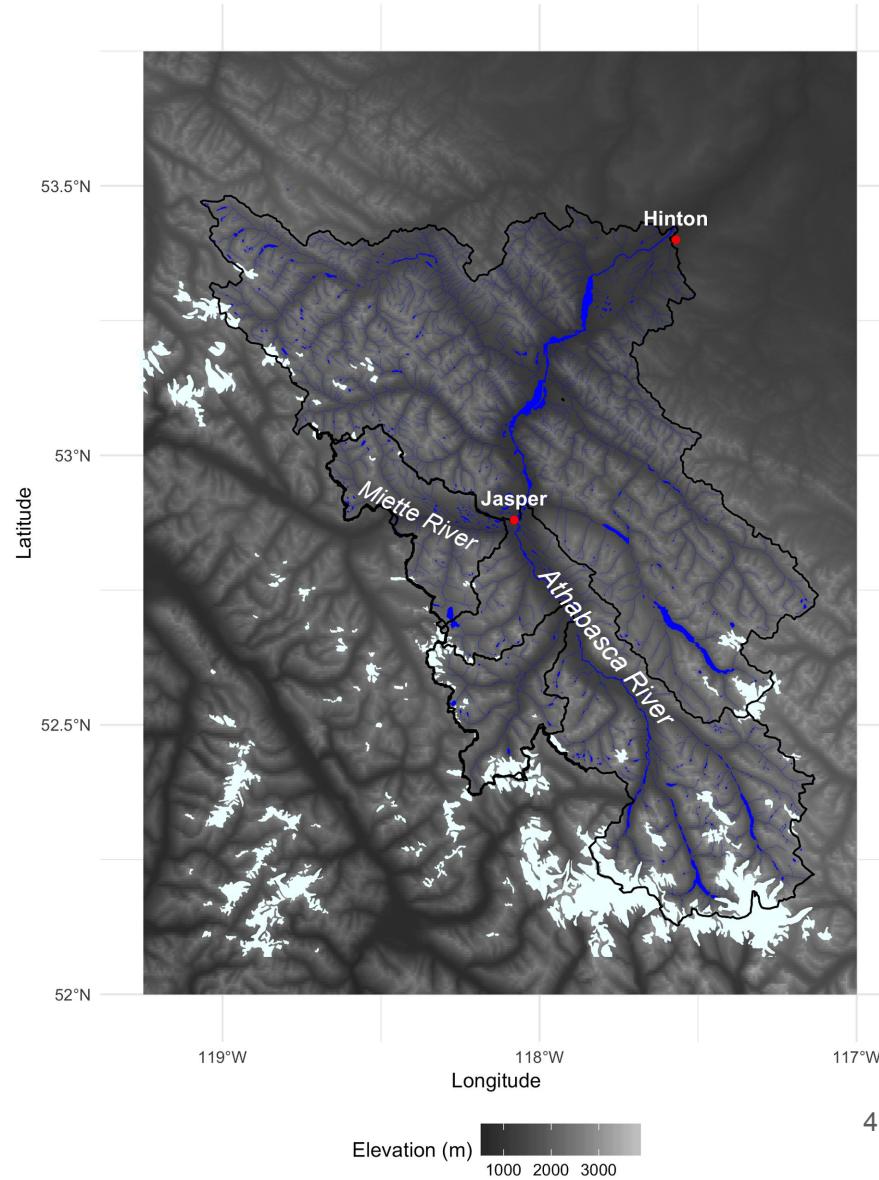
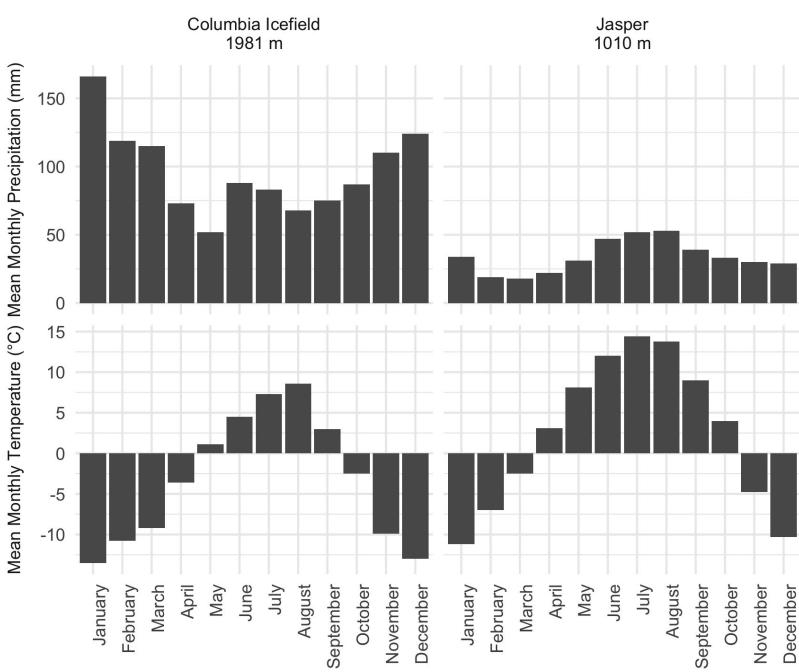


[Wikipedia Commons](#)



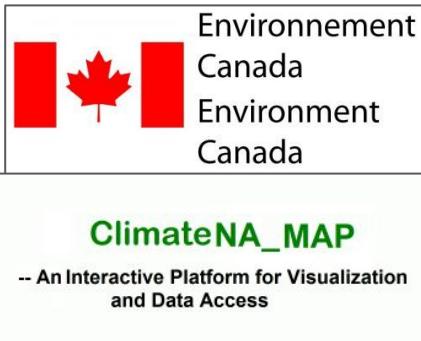
Athabasca River Headwaters

- Upstream of Hinton, AB ($9,720 \text{ km}^2$)
- Primarily forest and alpine cover,
- Glaciation primarily along southwest margins of watershed; currently covers
 - 2.8% of area upstream of Hinton,
 - 5.8% of area upstream of Jasper



Modelling Methods

Climate Data



Methodology is flexible!

Hydrological Modelling Framework



Miscellaneous
GIS Data

HRUs



Contributors to
Streamflow
(Tracer Routine)

Streamflow

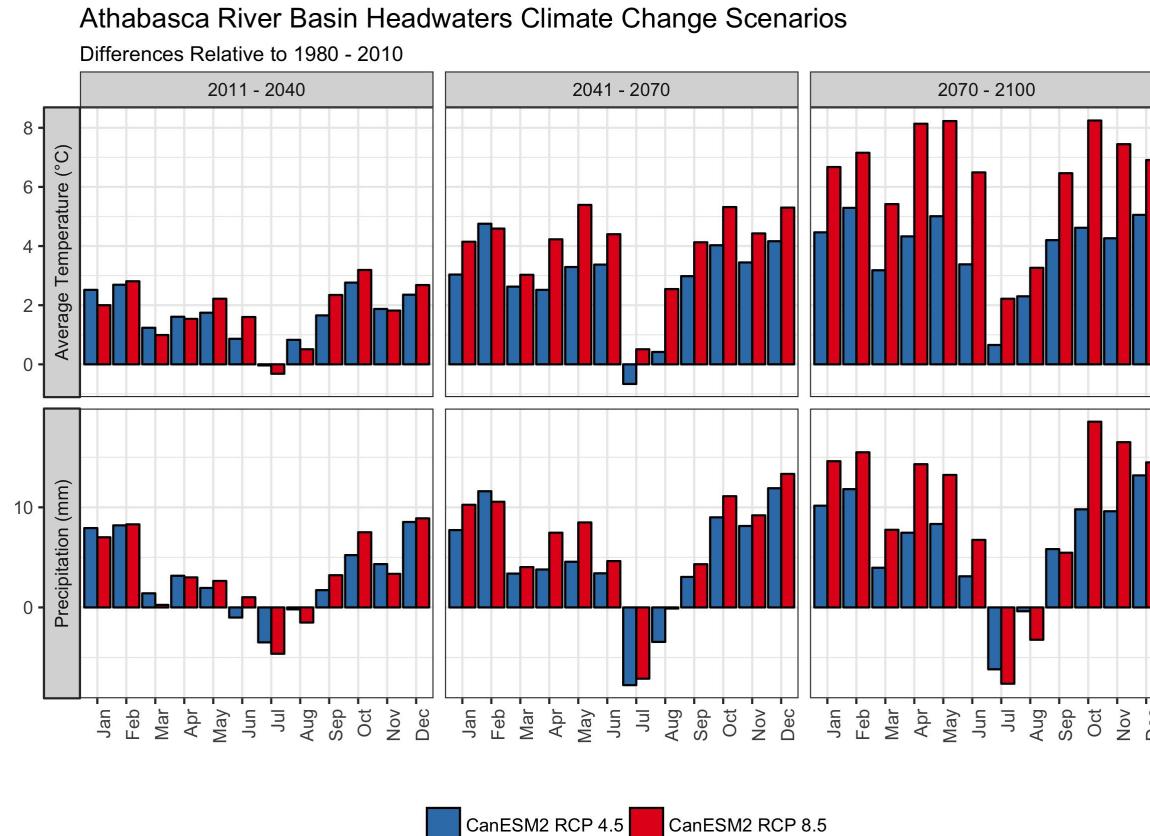
Snowpack,
Air Temperature,
Evaporation,
Soil moisture, etc.

Data Sources

- **Streamflow**
 - 3 Water Survey of Canada Hydrometric Gauges
 - Athabasca River near Jasper, at Hinton, and one major tributaries (Miette River)
- **Climate Data**
 - Four Environment Canada climate stations (Mica, Cariboo, Jasper, Hinton):
 - Missing data were imputed using nearby stations
 - Seven synthetic climate stations:
 - Scaled nearest observed met station using PRISM climate normals 1961-1990.
- **Land Cover**
 - [ABMI 2010 Land Cover](#) dataset, derived from Landsat
 - Glacier coverage
 - From Clarke, G. K., Jarosch, A. H., Anslow, F. S., Radić, V., & Menounos, B. (2015). Projected deglaciation of western Canada in the twenty-first century. *Nature Geoscience*, 8(5), 372-377.
 - http://couplet.unbc.ca/data/RGM_archive/

Climate Change Projections

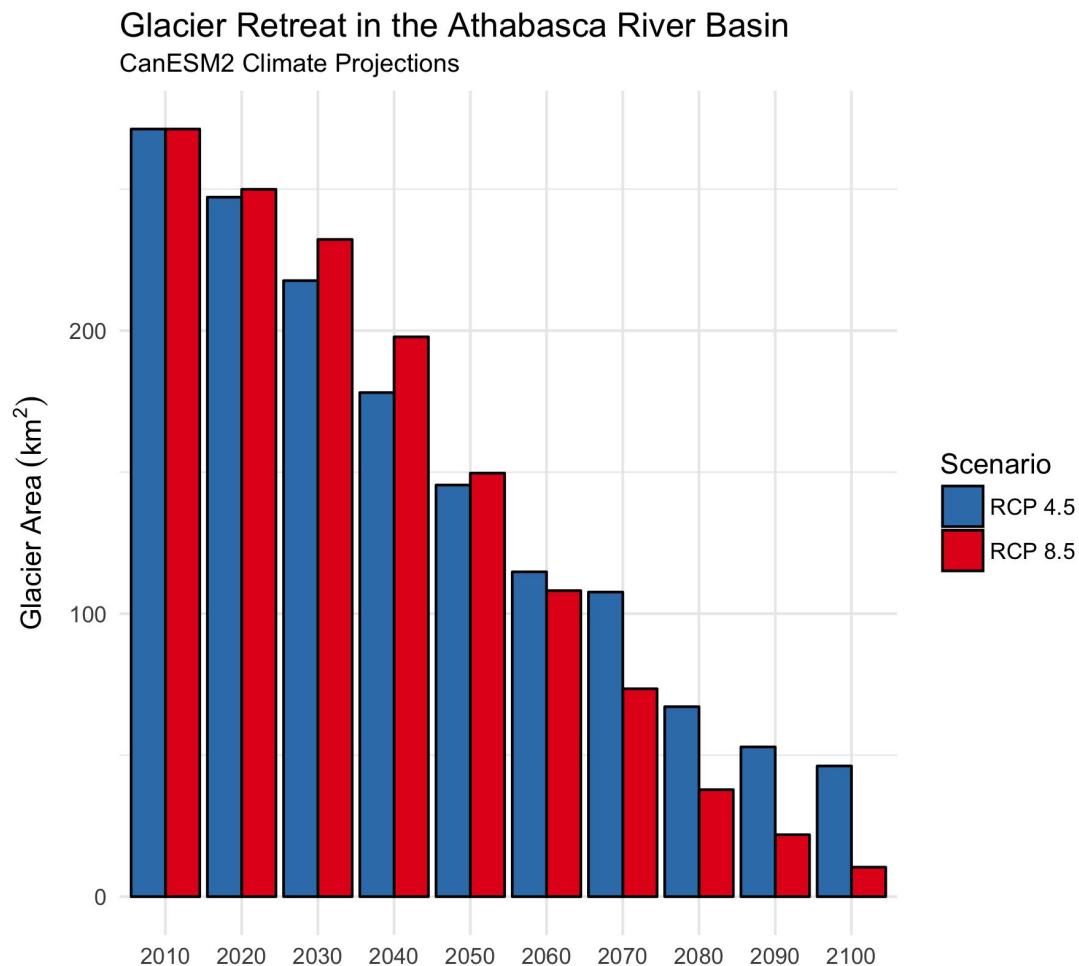
- CanESM2 RCP 4.5 and RCP 8.5 Scenarios from ClimateWNA
 - Three thirty year periods
 - Observed records scaled against differences between scenario and 1980 - 2010 normals



Climate Change Projections (cont.)

Glacier Area

- CanESM2 RCP 4.5 and RCP 8.5 Scenarios
- Implemented decadal changes from 2010 - 2100 into Raven

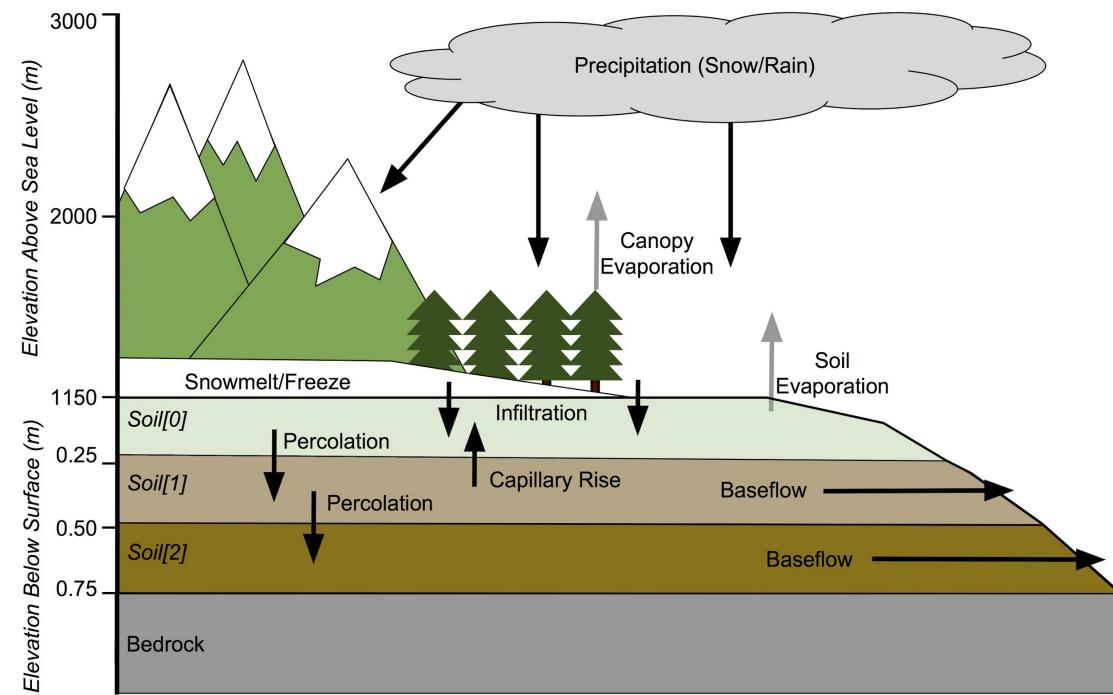


Data are obtained from Clarke, G. K., Jarosch, A. H., Anslow, F. S., Radić, V., & Menounos, B. (2015). Projected deglaciation of western Canada in the twenty-first century. *Nature Geoscience*, 8(5), 372-377.

Modified HBV-EC

Emulated in Raven, following the HBV-EC model with a few notable points:

- **Snow-melt:** spatially corrected Temperature Index Model that varies by day-length and is corrected by land cover type.
- **Glacier melt:** exposed ice uses scaled melt factor ($\sim x3.5$ snow)
- **Potential Evapotranspiration:** Priestley-Taylor equation
- **Baseflow:** (2-reservoir soil) lowest layer uses VIC algorithm



Model Calibration

- Calibrated using **OSTRICH**
 - Levenberg-Marquhart and DDS algorithms
 - Calibrated to Athabasca River at Hinton and Miette River at Jasper from 2000 - 2010
 - Verified from 1990 - 2010
- Step-like process to leverage multiple data sets and (hopefully!) improve hydrological process-representation

Guiding Principle	Parameters	Criteria/Objective
1) Isolate and exclude insensitive parameters	All	$CSS \approx 0$ ("not calculated")
2) Ensure correct volume of water in catchment	T, P lapse rates, Interception, glacier melt	Minimize PBIAS, maximize NSE
3) Ensure correct freshet timing	T lapse rate, melt factors	Maximize NSE, ensure SWE timing
4) Calibrate routing, sensitivity, and baseflow	Soil routing parameters	Maximize NSE
5) Approximate parameter uncertainty	All	Obtain parameter SE

Model Performance

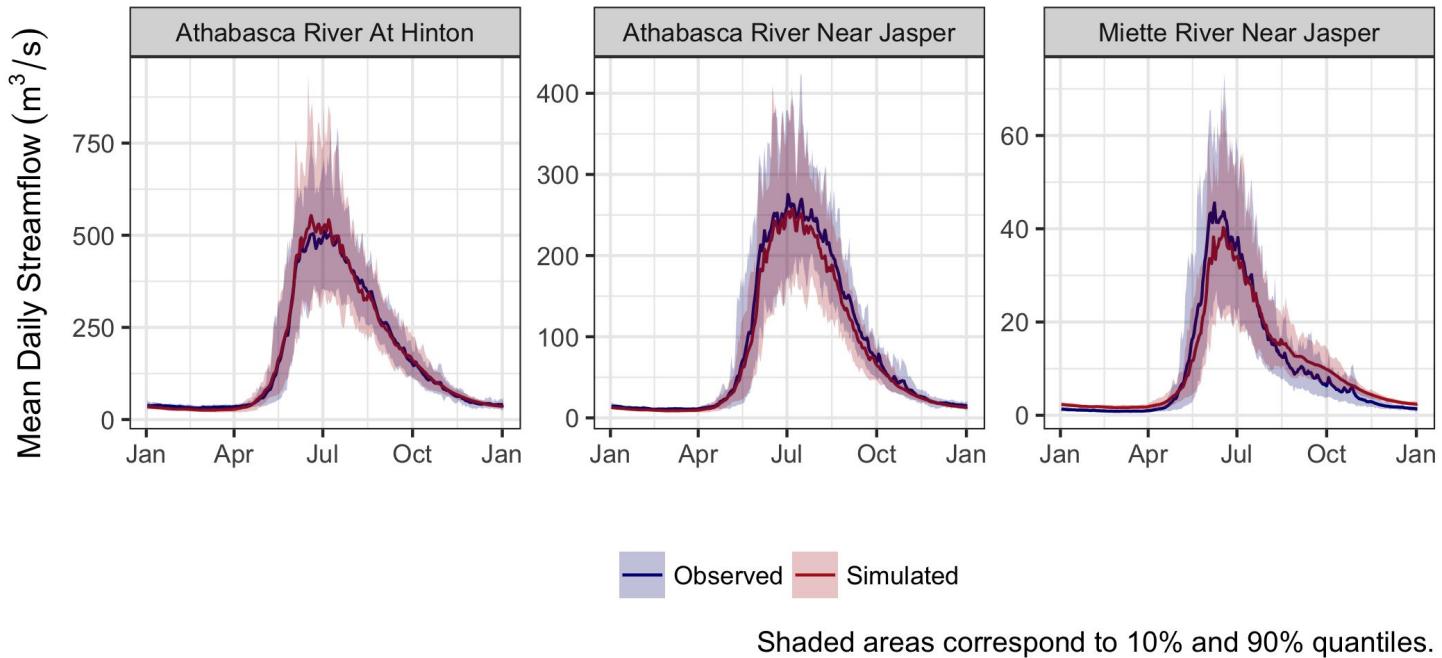


- Temperature/Precipitation Lapse Rates, Snowmelt parameters (and coniferous forest coverage) are most sensitive parameters
- Air Temperature and Snow Water Equivalent are well simulated

Site	Network	Elevation (m)	r^2		
			T	P	SWE
Sunwapta	EC, AB_EP	1416	0.87	-	0.63
Marmot Basin	EC, AB_EP	1800	0.93	0.71	0.63
Southesk	AB_EP	2045	-	-	0.82
Yellowhead	EC, BC_RFC	1847	0.89	-	0.92

Model Performance

Athabasca River Headwaters 1980 - 2015



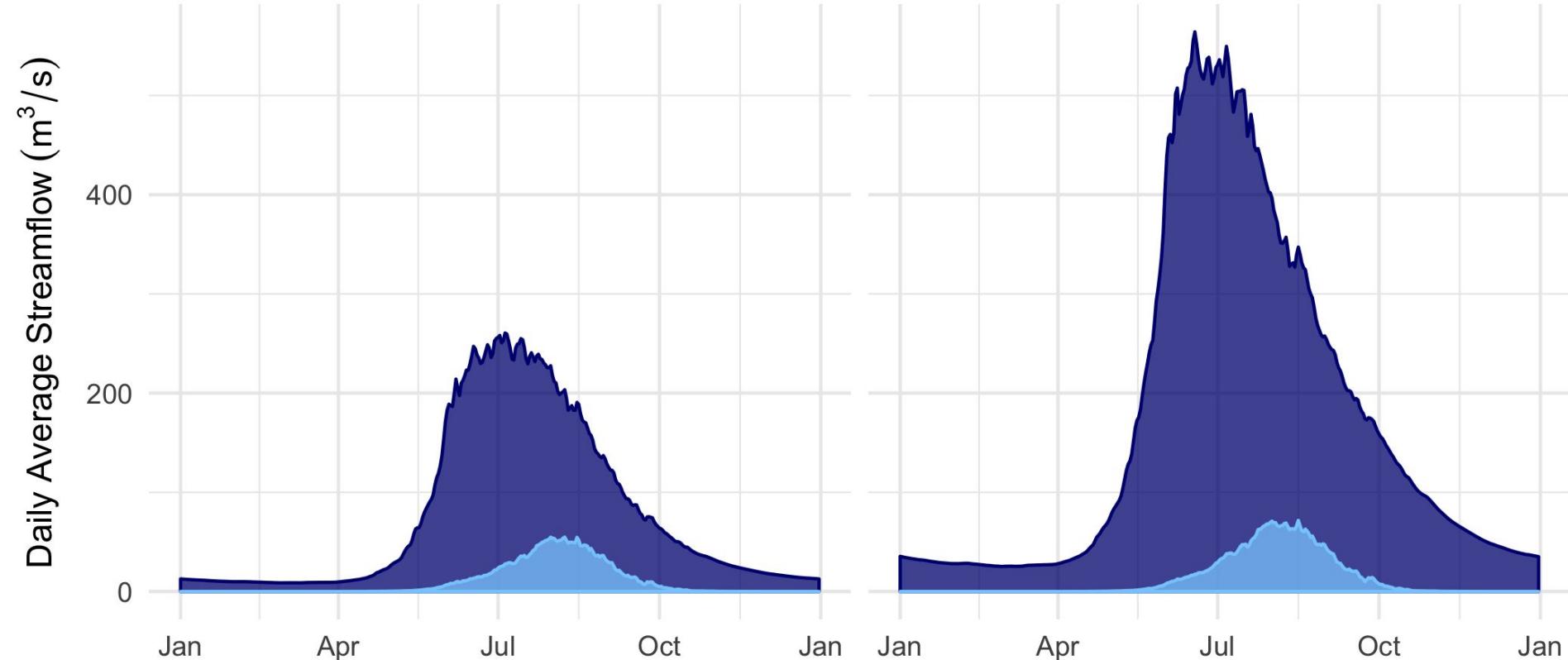
Site	Calibration		Verification	
	NSE	PBIAS	NSE	PBIAS
Athabasca River At Hinton	0.90	1%	0.91	1%
Athabasca River Near Jasper	-	-	0.93	-5%
Miette River Near Jasper	0.87	5%	0.86	2%

Current Glacier Contributions to Streamflow

1980 - 2010

Athabasca River Near Jasper

Athabasca River At Hinton



Glaciers currently account for up to 20-25% of flow in late summer

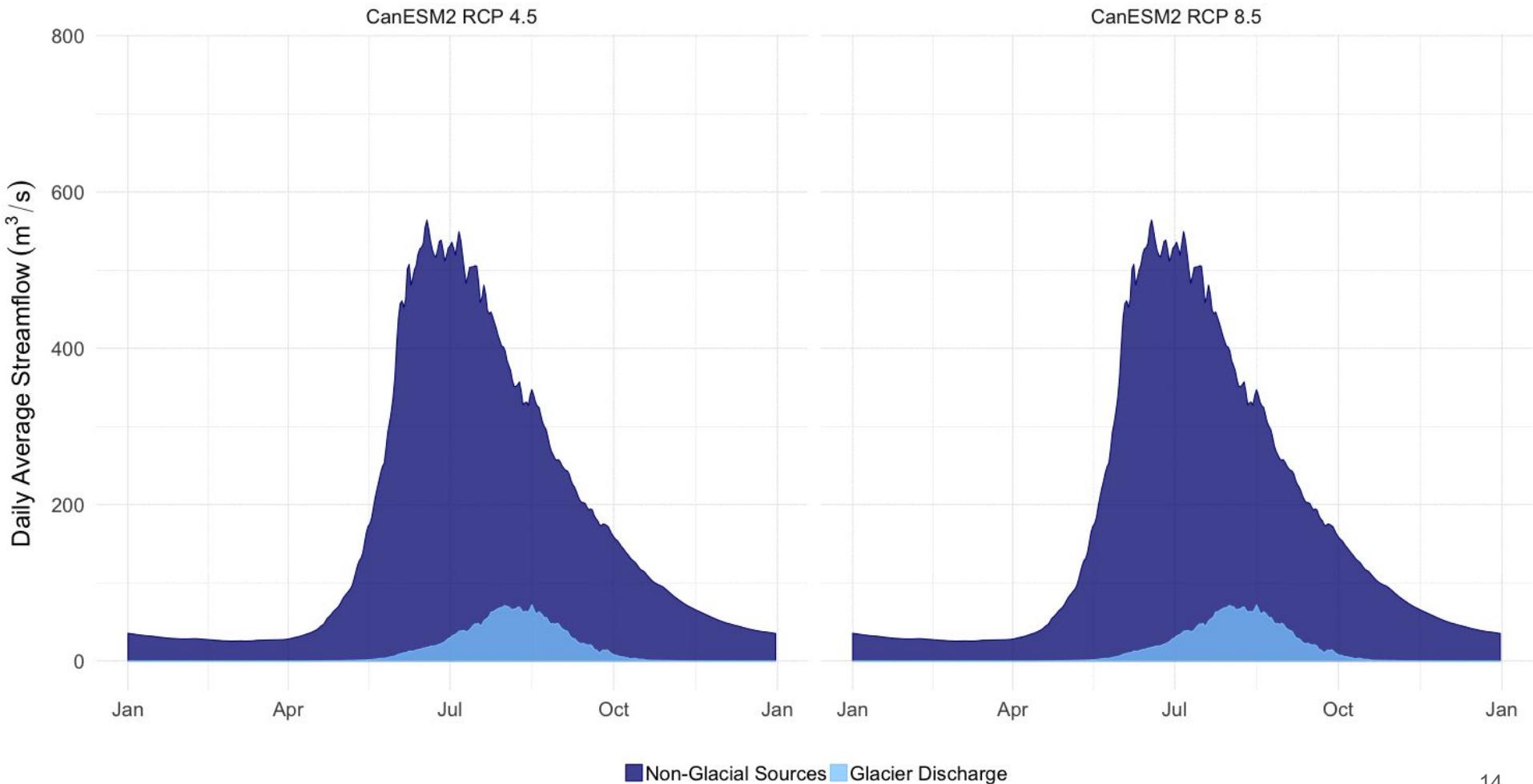
■ Non-Glacial Sources ■ Glacier Discharge

Obtained from Raven tracer routine

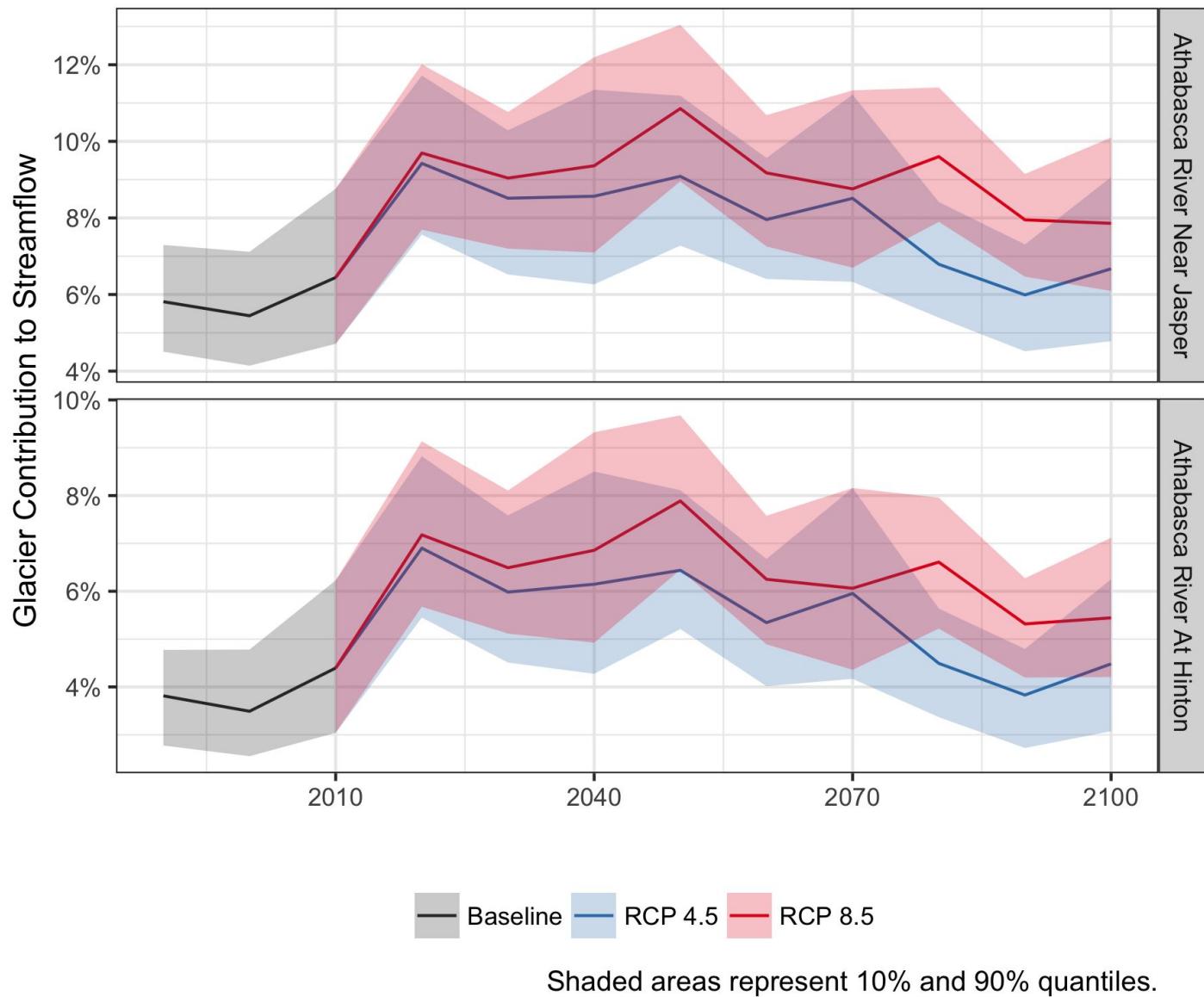
Glacier Contributions to Streamflow

Athabasca River At Hinton 1980 - 2010

Glacial Contributions to Streamflow

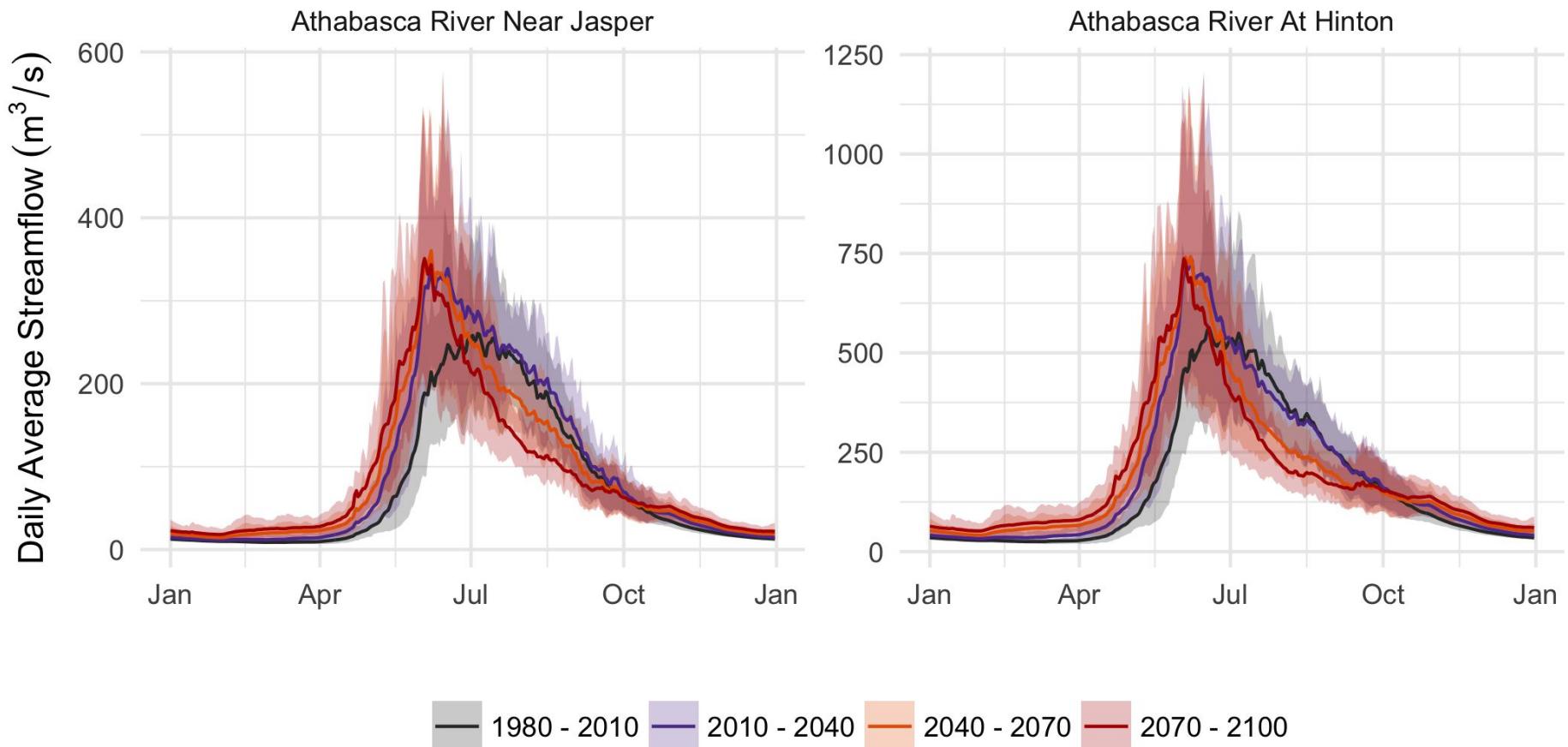


Glacier Contributions to Streamflow



Streamflow Under Future Conditions

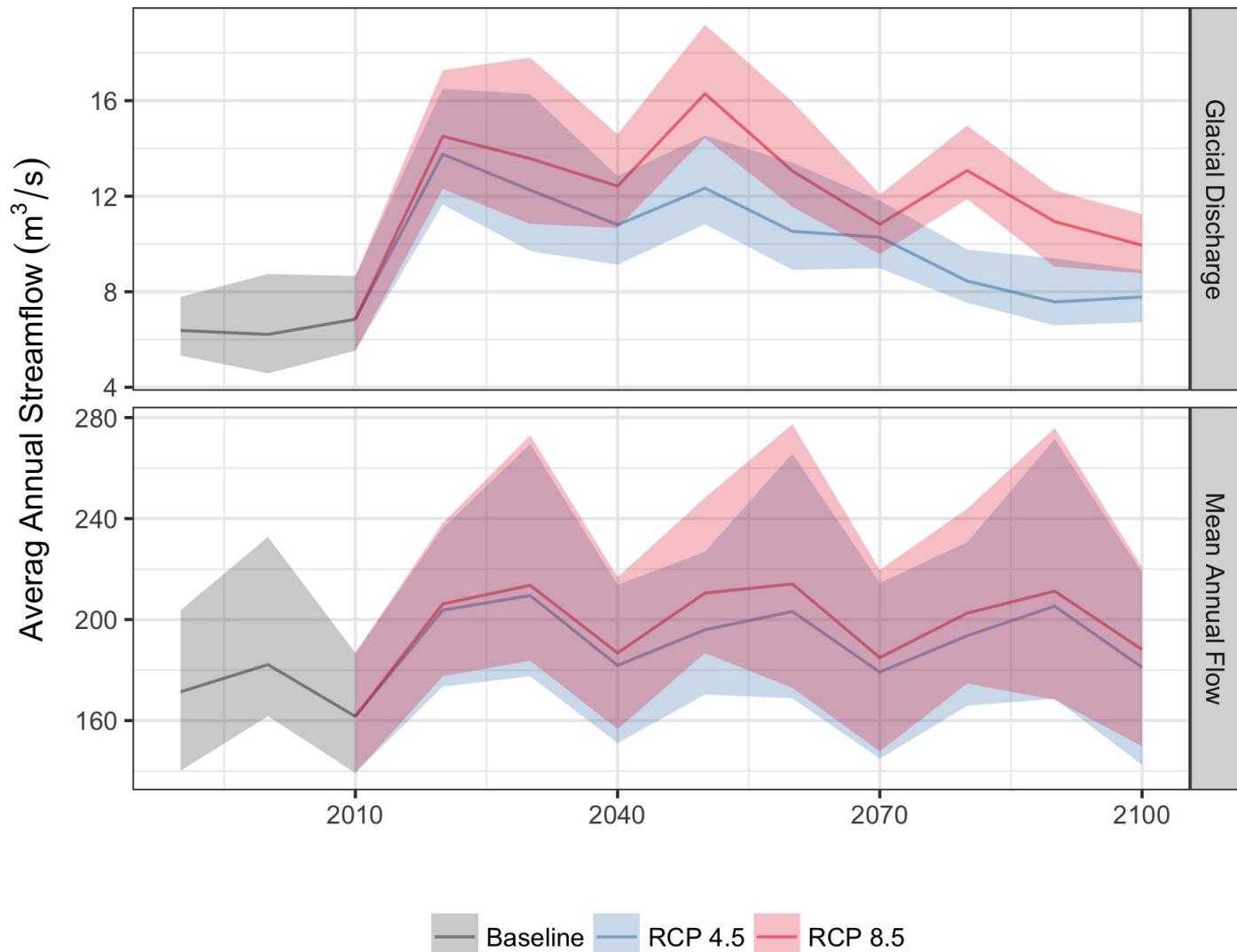
CanESM2 RCP 4.5



Shaded areas correspond to 90th and 10th quantiles.

Peak Water?

Athabasca River at Hinton



Implications and what (if anything) we do about it

Implications of less glacier area in the ARB

- Less August-September streamflow; typically a period where water shortages already occur downstream
 - Agricultural Demand
 - Industrial Licences
 - Municipal Use
 - Aboriginal Navigation

What can we do to offset reduced late-summer streamflow?

- Timing more critical than annual water yields
- Precautionary Withdrawal Limits/Reduce demands?
 - Demands expected to increase with more population, agriculture
- Build water storage (off-stream storage, dams)
- “[Switzerland Attempts to Conserve a Glacier by Covering It in Blankets](#)”
- “[Artificial glacier could help Ladakh villagers adapt to climate change](#)”

Conclusions

- **Glaciers are important in the ARB**
 - (for streamflow, but also a host of things not mentioned here)
 - Provide up to 20% of streamflow at Hinton in August, very little during the rest of the year
 - Glacier contributions occur mostly after freshet -- coincide with lower streamflow
- **Glacier contributions expected to increase in until 2050**
 - Double the contributions by 2050, but expected to decrease after that
- **Glacier coverage is expected to decrease**
 - ARB expected to lose about half its current glacier coverage by 2070, and for it to halve again by 2100
 - Shrinking glaciers mean less late-summer/fall water
- **Future streamflow expected to increase in spring, decrease in summer/fall**
 - Higher, earlier freshet (warmer temperatures increase rate and timing of snowmelt)
 - Less streamflow in August-September, larger changes further into future

Less streamflow during periods when water deficits are already common is likely to stress the system, will require adaptation or engineering solutions (or a combination of the two).

Acknowledgements

ARB Working group



Where can I find out more about this project?

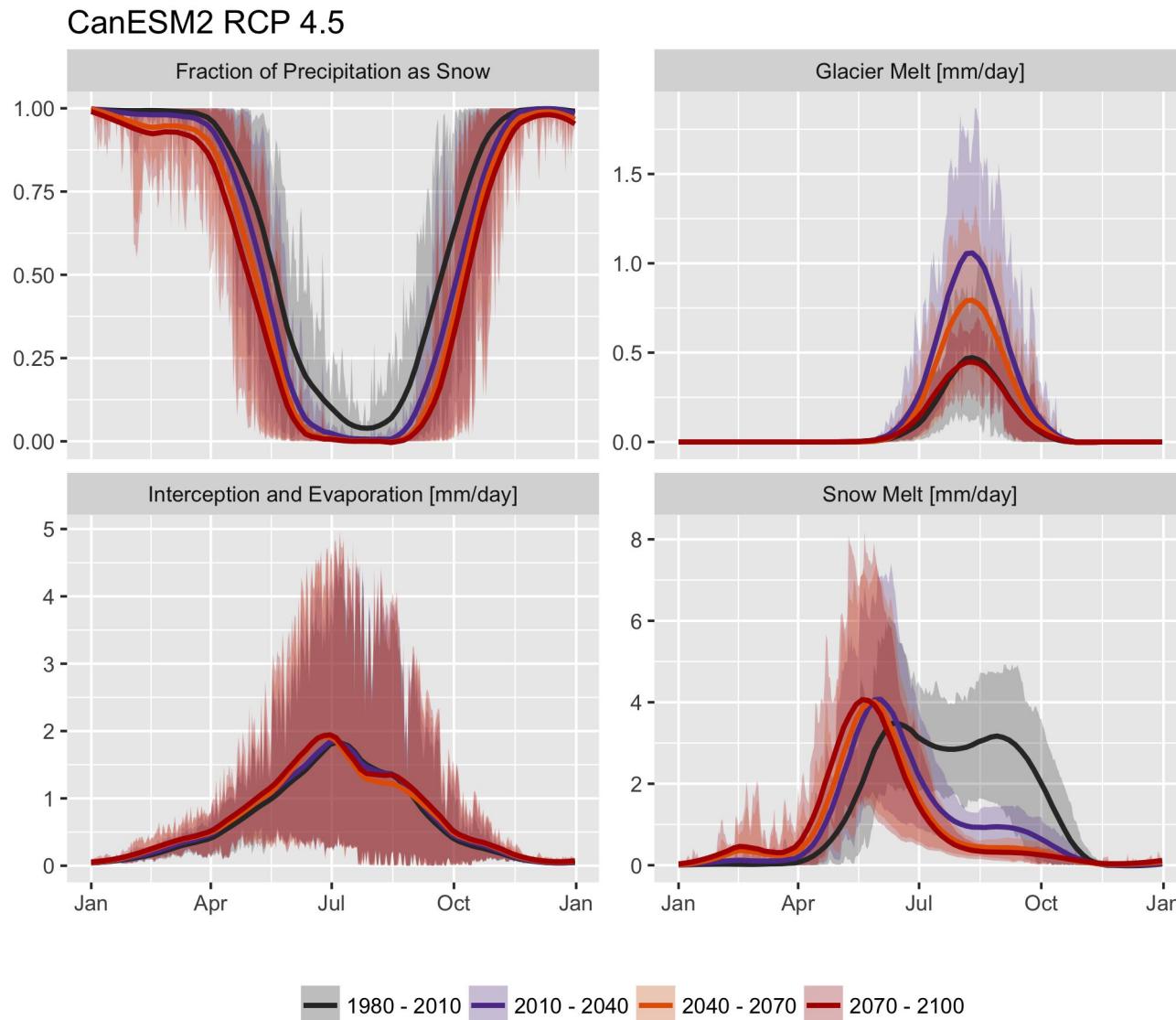
- [Google arb initiative](#)

Where can I get the slides for this?

- [LINK](#)



Water Balance Under Current and Future Conditions



Hydrologic Response Units (HRUs)

- In order to reduce computation time, complexity, the watershed is divided into HRUs.
- Within each sub-basin, proportion of each land cover type delineated by:
 - 100 m elevation bands (1000 - 3800 m)
 - Land cover type (Coniferous Forest, Deciduous Forest, Cut Forest, Grassland, Wetland, Mine, Disturbed (Urban), Alpine, and Glacier)
 - Aspect and Slope classes
- Glacier change: Decadal changes implemented within Raven
 - ‘GLACIER’ HRUs changed to ‘ALPINE’
- Resulted in 18,234 HRUs

